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Calibration of the Hertzsprung-Russell diagram in terms of age and mass for main-sequence B and A stars*

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Calculations of evolutionary model sequences for main-sequence B and A stars have been carried out by Tayler (1954), Kushwaha (1957), Blackler (1958), Henyey, LeLevier and Levee (1959), Hazelgrove and Hoyle (1959), and Hoyle (1960).

In recent years improved values of the energy generation function $\epsilon(\rho, T)$ and of the opacity function $k(\rho, T)$ have become available (cf. Caughlan and Fowler (1962), H. Reeves (1965), Cox (1965), and Arking and Herring (1965)). On this basis one of us (Kelsall 1965) has computed evolutionary model sequences of main-sequence stars for the mass range $\log M/M_{\odot}$ 0.20-0.85. These calculations were made for six different initial compositions (X, Y, Z).

The calibration of the Hertzsprung-Russell diagram in terms of age and mass for main-sequence B and A stars presented in this paper

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was derived from the results of the Kelsall evolutionary model sequence calculations. In this work $\epsilon(\rho, T)$ was taken as the sum of the ϵ-values for the proton-proton process and the CNO-cycle. For the larger masses the CNO-cycle contribution is much higher than the proton-proton contribution. It was assumed that the relative abundances of the C, N and O isotopes were those reached in equilibrium at the relevant temperature. The relative mass of N^{14} was taken as 0.6Z where Z is the relative mass of the heavy-element group (all elements except hydrogen and helium). The opacity function was computed according to the procedure described by Cox (1965), except that the absorption line contribution to the opacity was taken from the investigation by Arking and Herring (1965). For a series of combinations of X, Y and Z covering the range encountered in the stellar model calculations tables of the opacity due to continuous absorption and scattering as functions of the density ρ and the temperature T were computed with the Los Alamos high-speed computer code, kindly put at our disposal by Dr. A. Cox. Corrections to allow for the line effect according to Arking and Herring were applied to these values. For the stellar model calculations the opacity tables were stored in the computer memory, and the values of the opacity were obtained as required through computer interpolation in the tables.

For the mass range considered all models have a convective core, and there is radiative equilibrium everywhere outside the convective core. Complete mixing of the stellar material was assumed

within the convective core; and outside the convective core the effect of mixing was taken to be negligible. Following Hörm and Schwarzschild (1955) the dT/dr - dP/dr condition for convective instability valid in a chemically homogeneous medium was assumed to hold in the zone with continuously varying chemical composition that surrounds the convective core.

Evolutionary tracks through the hydrogen-burning phase were calculated for the following values of log $M/M_{\odot}$, namely, 0.20, 0.25, 0.45, 0.65, 0.85. For each mass they were made for the six initial chemical compositions specified below:

X	Y	Z
0.60	0.38	0.02
0.60	0.37	0.03
0.60	0.36	0.04
0.70	0.28	0.02
0.70	0.27	0.03
0.70	0.26	0.04

In the choice of the initial chemical compositions we were guided by the results of previous discussions of relative abundances in young population I (cf. Aller (1961), Henyey, LeLevier and Levee (1959), Haselgrove and Hoyle (1959), Morton (1959), Iben and Ehrman (1962), Eggen (1963), Iben (1963)).

The question of the initial values of X, Y, Z for the solar interior has been discussed by Osterbrock and Rogerson (1961) and by Gaustad (1964). Utilizing information on abundances within the heavy-element group in solar cosmic rays (Biswas, Fichtel, Guss and Waddington (1963)). Gaustad derived $Z/X = 0.028$ and found $X = 0.72$, $Y = 0.26$, and $Z = 0.02$. Following Gaustad in adopting $Z/X = 0.028$ Sears (1964) derived $X = 0.71$, $Y = 0.27$, $Z = 0.02$, while Demarque and Percy (1964) found $X = 0.70$, $Y = 0.28$, $Z = 0.020$ corresponding to $Z/X = 0.028$.

Comparison of the atmospheric abundances of metals relative to hydrogen in the sun on the one hand and young population I stars on the other (cf. Parker, Greenstein, Helfer and Wallerstein (1961) and Wallerstein (1962), also Strömgren (1963b)) suggests that the relevant range of Z for young population I stars is 0.02-0.04. With regard to the relative helium content Y for these stars it would be expected to be larger than, or equal to the value for the sun, i.e., $Y \geqq 0.26$. The ratio Y/Z should be smaller than or equal to the solar value, i.e., $Y/Z \leqq 14$. Also, since we expect $Z \leqq 0.04$ and $Y \geqq 0.26$, we presume that $Y/Z \geqq 6.5$.

For each set of values (M; X, Y, Z) an evolutionary model sequence was computed with time steps corresponding to values of X_c, the relative hydrogen content in the convective core, as given below:

For initial $X = 0.70$: $X_c = 0.70, 0.60, 0.50, 0.40, 0.30, 0.20, 0.10$

For initial $X = 0.60$; $X_c = 0.60, 0.50, 0.40, 0.30, 0.20, 0.10$

The evolutionary tracks for the last part of the hydrogen-burning

phase when $X_c < 0.05$ shows complications that are absent for the part convered by the calculations presented here (cf. Polak (1962) and Hayashi, Nishida and Sugimoto (1962). The tracks for very small X_c will be discussed separately by Kelsall. In neglecting the influence of the complications in question upon the age calibration we commit errors that are quite small statistically, since (1) the relative lifetime corresponding to $X_c < 0.05$ is only a few per cent of the total main-sequence lifetime and (2) the deviations of evolutionary tracks in the Hertzsprung-Russell diagram obtained by smooth extrapolation beyond $X_c \sim 0.1$ from the true tracks are never large.

The results of the calculations of the evolutionary tracks in the Hertzsprung-Russell diagram are given in Table 1. In constructing this table third-order polynomial interpolation between the directly computed values for log $M/M_\odot$ equal to 0.25, 0.45, 0.65, 0.85 was utilized to produce log T_e, M_{bol}, and log (Age) with the interval 0.05 in log $M/M_\odot$. Checks against directly computed values indicate that the inaccuracies introduced through the interpolation process are at most about two units in the last decimal place given in the table. The tabular values are given with 3 decimals in log T_e and 2 decimals in M_{bol} in order to reduce the rounding errors in the use of the tables to an insignificant amount.

For each initial chemical composition Table 1 gives as a function of log $M/M_\odot$ and X_c, the corresponding stellar age reckoned

from the start of hydrogen burning, the logarithm of the effective temperature T_e, the bolometric magnitude M_{bol}, and, finally, the quantity ΔM_{bol} which is defined as the difference between the bolometric magnitude on the zero-age line corresponding to T_e and the actual bolometric magnitude M_{bol}.

The numerical material for the calibration of the Hertzsprung-Russell diagram in terms of mass and age for main-sequence B and A stars is all contained in Table 1. For any of the six initial chemical compositions covered by the table the age and the mass can be found from given values of M_{bol} and log T_e through backward interpolation. Since the network of Table 1 is sufficiently dense for linear interpolation to yield quite satisfactory accuracy the numerical process in question is simple.

On the basis of the numerical values given in Table 1 diagrams giving curves of equal mass and equal age in a log T_e - M_{bol} plane have been constructed. Figures 1, 2, and 3 show the diagrams for the initial chemical compositions (0.70, 0.27, 0.03), (0.60, 0.37, 0.03), and (0.60, 0.36, 0.04).

The following discussion is based on the numerical data given in Table 1. Consider, first, the location of the zero-age line in the Hertzsprung-Russell diagram. Table 2 gives the zero-age lines through the tabulation of M_{bol} as a function of log T_e for the six different initial chemical compositions in question. Table 3 presents the zero-age line material arranged according to the relative hydrogen

content X and the helium-metal ratio Y/Z. Comparison of the two pairs of columns with equal Y/Z and different X shows that to a high degree of approximation the location of the zero-age line is a function of Y/Z only, independent of X, throughout the range of effective temperatures in question.

The last column of Table 3 contains the observed zero-age line, derived in the form of a log T_e - M_{bol} relation from the observed relation between color index and M_v with a temperature scale and bolometric corrections obtained on the basis of model-atmosphere calculations. As stated above, we expect Y/Z to fall in the range 6.5 to 14. Comparison of the observed and the computed log T_e - M_{bol} relations as presented in Table 3 suggests that the representative value of Y/Z for young population I is closer to the lower limit 6.5 than to the upper limit. However, the variation of the location of the zero-age line with Y/Z is not large, and Y/Z cannot be very accurately determined in this fashion. Indeed, if we choose the value Y/Z = 9 to represent the whole range of plausible Y/Z - values, then we predict -- without adjustment of any parameter -- a zero-age line that agrees with the observed practically within the uncertainty of the latter; and the maximum uncertainty in the prediction due to the possible deviation of the actual Y/Z - value from the chosen value is only about $0^m.2$. In this fashion we obtain a test of the computed zero-age models. The result is quite satisfactory.

Next, let us consider the mass-luminosity relation on the zero-age line for the different initial chemical compositions in question. Table 4 gives M_{bol} on the zero-age line as a function of $\log M/M_\odot$ for the different chemical compositions, arranged according to X and Y/Z. Where the location of the zero-age line in the Hertzsprung-Russell diagram is insensitive to X and depends on Y/Z the zero-age mass-luminosity relation is more sensitive to X than to Y/Z.

Sirius A is close to the zero-age line. With the values of M_{bol} and $\log M/M_\odot$ given by Harris, Strand and Worley (1963), we find through projection on the zero-age line along the relevant evolutionary track given by Table 1 that the zero-age value of M_{bol} corresponding to the mass of Sirius A ($\log M/M_\odot = 0.33$) is $1^m.2$. With $Y/Z = 9.0$ we then find from Table 4 a value of X equal to 0.68, while the assumption $Y/Z = 6.5$ gives $X = 0.64$.

For a number of spectroscopic binaries for which the mass, the effective temperature and the bolometric magnitude are known with good, or fair accuracy values of X have been derived through the procedure just indicated. The results are to be discussed in a separate investigation. Here we wish to mention that the X-values generally fall in the range 0.6-0.7, although X-values between 0.5 and 0.6 do occur. In this connection we refer to results obtained by Eggen (1963) for F and G type visual binaries (outside the range of the calibration presented here) in the Hyades. Eggen's results suggest a lower X-value

for the Hyades, around X = 0.5. In this connection it should be noted that our age and mass calibration can be extrapolated without serious loss of accuracy to X-values as low as about 0.5.

While Table 1 gives log T_e, M_{bol} and stellar age with the arguments log $M/M_\odot$ and X_c, Table 5 presents equivalent information in the form of a tabulation of log T_e and ΔM_{bol} with the arguments log (Age) and X_c. Thus, Table 1 contains the data for the construction of curves of equal mass in the Hertzsprung-Russell diagram, whereas Table 5 is convenient in drawing curves of equal age. We have chosen to tabulate log (Age) rather than Age in Table 5 because interpolation is then somewhat more convenient except in the immediate neighborhood of the zero-age line.

Figures 1, 2 and 3 illustrate the well-known fact that age determination from log T_e and M_{bol} is more accurate in the upper part of the main-sequence band than in the lower, because the distances between lines of equal age generally increase with distance from the zero-age line. Figures 1, 2 and 3 also show that the curves of equal age are very nearly straight vertical lines in the upper 40 per cent of the main-sequence band, i.e., when ΔM_{bol} is larger than 0.6 times the width of the main-sequence band at the effective temperature in question. We shall make use of this very convenient feature of the age-calibration curves in the following discussions of age determination for stars in the upper 40-per cent of the main-sequence band.

Inspection of the log T_e-columns of Table 5 shows that the

differences between the log T_e-values for the same value of log(Age) (and the same initial chemical composition) but different X_c-values average only a few units in the third decimal when ΔM_{bol} is larger than 0.6 times the main-sequence width. Table 6 gives values for log T_e as a function of log (Age) which are valid to a very good approximation in the upper 40-per cent of the main-sequence band. The values of log(Age) are given for three different compositions, namely, (0.70, 0.27, 0.03), (0.60, 0.37, 0.03) and (0.60, 0.36, 0.04). Comparison of the first two log T_e-columns shows the effect upon the resulting age of a change in the assumed relative hydrogen content X, while the two last columns serve the analogous purpose for the case of change in the relative heavy-element content Z.

When the temperature scale valid for stars in the upper 40-per cent of the main-sequence band is known Table 6 can be converted into a table giving log (Age) as a function of an intrinsic color index. For the spectral range B2 to B8 the relation between T_e and the intrinsic color index $(u - b)_o$ of the system of photoelectric uvby photometry (cf. Strömgren (1963a) and (1963b)) has been derived on the basis of model-atmosphere calculations (Strömgren (1964)). The relation between the intrinsic color indices $(U - B)_o$ and $(u - b)_o$ is known from observations. Hence the stellar age can be tabulated--again for the upper 40-per cent of the main-sequence band--as a function of $(U - B)_o$ or $(u - b)_o$. Table 7 gives the relation between $(U - B)_o$, $(u - b)_o$ and the age for the initial chemical composition (0.70, 0.27, 0.03).

It is clear that Tables 6 or 7 can be used for age determination of clusters and associations that contain stars which have evolved into the upper 40-per cent of the main-sequence band when these stars are in the ranges of T_e covered by the tables. We proceed to discuss the case of age determination for field stars of spectral type B on the basis of photoelectric UBV and Hβ photometry (cf. Crawford (1958) and Strömgren (1958)).

When the location of a star in Crawford's $(U - B)_0$ -β diagram for B stars is known the effective temperature T_e and the bolometric magnitude M_{bol} can be evaluated, and the age can be found from Table 1 or Table 5. If the location in the $(U - B)_0$ -β diagram is such that the star is in the upper 40-per cent part of the main-sequence band, then the corresponding age is practically independent of β, and it can be found from $(U - B)_0$ with the help of Table 7, or an analogous table valid for the chosen initial chemical composition.

Let us consider now the accuracy of the age determination in the latter case. Assuming the probably error of $(U - B)_0$ to be $\pm 0^m.01$ we find for B2 - B8 stars an average p.e. of the age equal to 4-per cent. If for the stars in question the r.m.s. deviation of X from an average value is 0.05, the corresponding uncertainty of the age according to Table 6 gives a p.e. contribution of about 2-per cent of the age. Similarly, if the r.m.s. deviation of Z from an average value is less than or equal to 0.01 (cf. Strömgren (1963a)),

then the corresponding probable-error contribution is $\leqq$ 7-per cent.

While this discussion suggests that ages of very satisfactory accuracy can be obtained for stars in the favorable region of the Hertzsprung-Russell diagram just considered, it should be emphasized that our age calibration has been derived on the assumption that the stars are non-rotating and that the structure is not influenced by magnetic fields. Therefore, the actual uncertainty may be considerably greater than the uncertainties corresponding to the sources of error just discussed. Investigations based on precision photometry for stars in clusters and associations of the r.m.s. scatter of $(U - B)_o$ in the upper 40-per cent part of the main-sequence band should contribute to the clarification of this question.

For A stars later than A2 age determination for field stars can be carried out in an analogous way on the basis of photoelectric uvby and Hβ photometry use being made of a c_1 -β diagram (cf. Strömgren (1958) and 1963b)). For unreddened stars a c_1 - (b - y) diagram served the same purpose (Strömgren (1963a)). For stars around A0 the problem is more difficult, but it is solved when the location of the star in a $(B - V)_o$ -β diagram can be determined (cf. e.g., Strömgren (1963b)).

Applications of the procedures for age determination of main-sequence B and A stars described in this paper are discussed in a separate investigation.

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Table 1

X = 0.60 Y = 0.38 Z = 0.02

$X_c = 0.50$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	129	4.007	$+1^m.31$	$0^m.20$
0.30	97	4.042	+0.82	0.20
0.35	73	4.076	+0.33	0.21
0.40	55	4.110	-0.14	0.21
0.45	41.7	4.142	-0.62	0.22
0.50	31.8	4.174	-1.08	0.22
0.55	24.4	4.205	-1.54	0.23
0.60	18.9	4.235	-1.99	0.24
0.65	14.7	4.265	-2.43	0.23
0.70	11.5	4.294	-2.87	0.22
0.75	9.1	4.322	-3.30	0.22
0.80	7.3	4.349	-3.72	0.22
0.85	5.9	4.376	-4.13	0.21

$X_c = 0.40$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	233	3.997	$+1^m.24$	$0^m.41$
0.30	174	4.032	+0.74	0.42
0.35	131	4.066	+0.25	0.44
0.40	98	4.099	-0.23	0.45
0.45	74	4.132	-0.71	0.46
0.50	57	4.164	-1.18	0.47
0.55	43.5	4.195	-1.64	0.48
0.60	33.5	4.226	-2.09	0.48
0.65	26.1	4.256	-2.54	0.47
0.70	20.5	4.285	-2.98	0.47
0.75	16.2	4.313	-3.42	0.48
0.80	12.9	4.341	-3.84	0.47
0.85	10.5	4.368	-4.26	0.47

$X_c = 0.30$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	318	3.984	$+1^m.18$	$0^m.64$
0.30	237	4.019	+0.68	0.66
0.35	177	4.053	+0.19	0.68
0.40	133	4.087	-0.30	0.69
0.45	100	4.120	-0.78	0.70
0.50	76	4.152	-1.26	0.72
0.55	58	4.183	-1.73	0.74
0.60	45.1	4.214	-2.19	0.75
0.65	35.0	4.244	-2.64	0.76
0.70	27.4	4.274	-3.08	0.75
0.75	21.7	4.303	-3.52	0.74
0.80	17.4	4.331	-3.95	0.73
0.85	14.0	4.358	-4.37	0.73

$X_c = 0.20$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	387	3.970	$+1^m.14$	$0^m.87$
0.30	287	4.004	+0.63	0.92
0.35	214	4.038	+0.14	0.94
0.40	161	4.072	-0.36	0.96
0.45	121	4.105	-0.84	0.97
0.50	92	4.138	-1.32	0.98
0.55	70	4.169	-1.80	1.00
0.60	54	4.201	-2.26	1.02
0.65	42.0	4.231	-2.72	1.04
0.70	32.9	4.261	-3.17	1.03
0.75	26.0	4.290	-3.61	1.03
0.80	20.8	4.318	-4.05	1.03
0.85	16.8	4.345	-4.47	1.03

$X_c = 0.10$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	442	3.956	$+1^m.10$	$1^m.10$
0.30	327	3.990	+0.60	1.14
0.35	244	4.024	+0.10	1.17
0.40	182	4.057	-0.40	1.21
0.45	137	4.091	-0.89	1.23
0.50	104	4.124	-1.38	1.24
0.55	79	4.156	-1.85	1.26
0.60	61	4.187	-2.33	1.28
0.65	47.3	4.218	-2.79	1.30
0.70	37.1	4.248	-3.24	1.30
0.75	29.4	4.277	-3.69	1.31
0.80	23.5	4.305	-4.13	1.32
0.85	19.0	4.332	-4.56	1.33

Table 1 (continued)

X = 0.60 Y = 0.37 Z = 0.03

$X_c = 0.50$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	139	3.977	$+1^m.49$	$0^m.19$
0.30	104	4.012	+0.99	0.21
0.35	78	4.047	+0.50	0.21
0.40	59	4.082	+0.01	0.21
0.45	44.4	4.116	-0.47	0.22
0.50	33.7	4.148	-0.94	0.23
0.55	25.8	4.181	-1.41	0.23
0.60	19.8	4.212	-1.87	0.23
0.65	15.4	4.243	-2.33	0.23
0.70	12.0	4.273	-2.78	0.23
0.75	9.5	4.302	-3.21	0.22
0.80	7.6	4.330	-3.64	0.22
0.85	6.1	4.358	-4.06	0.22

$X_c = 0.40$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	253	3.966	$+1^m.43$	$0^m.40$
0.30	188	4.002	-0.93	0.41
0.35	141	4.037	+0.43	0.42
0.40	106	4.071	-0.06	0.44
0.45	80	4.105	-0.55	0.45
0.50	60	4.138	-1.03	0.46
0.55	46.0	4.171	-1.51	0.47
0.60	35.3	4.202	-1.97	0.48
0.65	27.4	4.233	-2.43	0.48
0.70	21.4	4.263	-2.88	0.48
0.75	16.8	4.293	-3.33	0.48
0.80	13.4	4.322	-3.76	0.47
0.85	10.8	4.350	-4.19	0.47

$X_c = 0.30$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	347	3.953	$+1^m.38$	$0^m.62$
0.30	258	3.989	+0.87	0.64
0.35	192	4.024	+0.37	0.66
0.40	144	4.058	-0.13	0.69
0.45	108	4.092	-0.62	0.70
0.50	82	4.125	-1.10	0.72
0.55	62	4.158	-1.58	0.73
0.60	47.6	4.190	-2.06	0.75
0.65	36.8	4.221	-2.52	0.75
0.70	28.7	4.252	-2.98	0.74
0.75	22.6	4.282	-3.42	0.73
0.80	18.0	4.311	-3.86	0.73
0.85	14.5	4.339	-4.30	0.74

$X_c = 0.20$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	424	3.938	$+1^m.35$	$0^m.86$
0.30	313	3.974	+0.84	0.88
0.35	233	4.009	+0.33	0.91
0.40	174	4.043	-0.17	0.94
0.45	130	4.077	-0.67	0.96
0.50	98	4.111	-1.16	0.98
0.55	75	4.144	-1.64	0.99
0.60	57	4.176	-2.12	1.01
0.65	44.3	4.207	-2.59	1.02
0.70	34.5	4.238	-3.05	1.02
0.75	27.2	4.268	-3.51	1.03
0.80	21.6	4.297	-3.95	1.03
0.85	17.4	4.326	-4.39	1.03

$X_c = 0.10$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	485	3.924	$+1^m.33$	$1^m.07$
0.30	359	3.959	+0.81	1.11
0.35	266	3.994	+0.30	1.15
0.40	198	4.029	-0.21	1.17
0.45	148	4.063	-0.71	1.20
0.50	112	4.097	-1.20	1.22
0.55	85	4.130	-1.69	1.24
0.60	65	4.162	-2.17	1.26
0.65	50	4.194	-2.65	1.28
0.70	39.0	4.225	-3.12	1.29
0.75	30.7	4.255	-3.58	1.30
0.80	24.4	4.284	-4.03	1.31
0.85	19.7	4.312	-4.47	1.33

Table 1 (continued)
X = 0.60 Y = 0.36 Z = 0.04

$X_c = 0.50$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	149	3.953	$+1^m.64$	$0^m.19$
0.30	111	3.989	+1.14	0.20
0.35	83	4.025	+0.64	0.21
0.40	62	4.060	+0.14	0.22
0.45	46.9	4.095	-0.35	0.22
0.50	35.5	4.129	-0.83	0.22
0.55	27.0	4.162	-1.31	0.22
0.60	20.7	4.194	-1.78	0.23
0.65	15.9	4.226	-2.24	0.23
0.70	12.4	4.257	-2.70	0.23
0.75	9.8	4.287	-3.14	0.23
0.80	7.7	4.316	-3.58	0.23
0.85	6.2	4.344	-4.01	0.24

$X_c = 0.40$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	272	3.942	$+1^m.59$	$0^m.38$
0.30	202	3.978	+1.08	0.41
0.35	151	4.014	+0.57	0.43
0.40	113	4.049	+0.07	0.44
0.45	84	4.084	-0.42	0.44
0.50	64	4.118	-0.91	0.46
0.55	48.3	4.151	-1.40	0.47
0.60	36.9	4.184	-1.87	0.48
0.65	28.4	4.216	-2.34	0.48
0.70	22.1	4.247	-2.80	0.48
0.75	17.3	4.277	-3.25	0.48
0.80	13.8	4.307	-3.69	0.48
0.85	11.1	4.336	-4.13	0.48

$X_c = 0.30$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	374	3.929	$+1^m.55$	$0^m.59$
0.30	277	3.965	+1.04	0.63
0.35	206	4.001	+0.53	0.66
0.40	153	4.036	+0.02	0.68
0.45	115	4.071	-0.48	0.69
0.50	86	4.105	-0.98	0.71
0.55	65	4.139	-1.47	0.72
0.60	50	4.171	-1.95	0.74
0.65	38.3	4.204	-2.42	0.74
0.70	29.7	4.235	-2.89	0.74
0.75	23.3	4.265	-3.34	0.74
0.80	18.5	4.295	-3.79	0.75
0.85	14.9	4.324	-4.23	0.76

$X_c = 0.20$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	458	3.914	$+1^m.54$	$0^m.80$
0.30	339	3.950	+1.01	0.86
0.35	251	3.986	+0.49	0.90
0.40	187	4.021	-0.02	0.93
0.45	139	4.056	-0.53	0.95
0.50	104	4.090	-1.03	0.97
0.55	79	4.124	-1.52	0.98
0.60	60	4.157	-2.01	1.00
0.65	46.1	4.189	-2.49	1.01
0.70	35.8	4.221	-2.96	1.02
0.75	28.1	4.252	-3.42	1.03
0.80	22.3	4.281	-3.88	1.05
0.85	17.9	4.310	-4.32	1.06

$X_c = 0.10$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	527	3.901	$+1^m.51$	$0^m.99$
0.30	388	3.936	+0.99	1.06
0.35	287	3.971	+0.47	1.12
0.40	213	4.006	-0.05	1.17
0.45	159	4.041	-0.56	1.19
0.50	119	4.075	-1.07	1.22
0.55	90	4.109	-1.57	1.24
0.60	68	4.142	-2.06	1.26
0.65	52	4.175	-2.55	1.28
0.70	40.5	4.207	-3.02	1.29
0.75	31.7	4.237	-3.49	1.31
0.80	25.2	4.267	-3.95	1.33
0.85	20.2	4.296	-4.40	1.35

Table 1 (continued)

X = 0.70 Y = 0.28 Z = 0.02

$X_c = 0.60$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	196	3.955	$+1^m.86$	$0^m.16$
0.30	148	3.991	+1.36	0.18
0.35	111	4.027	+0.87	0.18
0.40	84	4.061	+0.39	0.18
0.45	64	4.095	-0.09	0.18
0.50	48.4	4.127	-0.56	0.19
0.55	37.1	4.159	-1.03	0.19
0.60	28.5	4.190	-1.48	0.20
0.65	22.0	4.221	-1.94	0.20
0.70	17.1	4.250	-2.38	0.20
0.75	13.5	4.279	-2.82	0.20
0.80	10.6	4.307	-3.25	0.21
0.85	8.5	4.335	-3.67	0.20

$X_c = 0.50$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	360	3.947	$+1^m.80$	$0^m.31$
0.30	270	3.983	+1.30	0.34
0.35	203	4.018	+0.80	0.37
0.40	153	4.052	+0.31	0.39
0.45	115	4.086	-0.17	0.39
0.50	88	4.118	-0.64	0.41
0.55	67	4.150	-1.11	0.41
0.60	51	4.182	-1.58	0.42
0.65	39.5	4.212	-2.03	0.43
0.70	30.7	4.242	-2.48	0.42
0.75	24.0	4.271	-2.92	0.42
0.80	19.0	4.299	-3.36	0.43
0.85	15.2	4.327	-3.78	0.43

$X_c = 0.40$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	497	3.937	$+1^m.75$	$0^m.49$
0.30	371	3.972	+1.24	0.54
0.35	278	4.007	+0.75	0.57
0.40	208	4.041	+0.25	0.60
0.45	157	4.074	-0.23	0.62
0.50	119	4.107	-0.71	0.63
0.55	90	4.139	-1.19	0.65
0.60	69	4.171	-1.66	0.66
0.65	53	4.202	-2.12	0.67
0.70	41.4	4.232	-2.57	0.67
0.75	32.4	4.261	-3.02	0.68
0.80	25.6	4.290	-3.45	0.67
0.85	20.5	4.318	-3.88	0.67

$X_c = 0.30$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	610	3.924	$+1^m.72$	$0^m.69$
0.30	455	3.959	+1.21	0.74
0.35	340	3.993	+0.71	0.80
0.40	254	4.027	+0.21	0.83
0.45	191	4.061	-0.28	0.86
0.50	144	4.094	-0.77	0.88
0.55	110	4.126	-1.25	0.90
0.60	84	4.158	-1.72	0.92
0.65	64	4.189	-2.19	0.92
0.70	50	4.219	-2.64	0.93
0.75	39.1	4.249	-3.10	0.94
0.80	30.9	4.278	-3.54	0.94
0.85	24.7	4.306	-3.97	0.95

$X_c = 0.20$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	710	3.910	$-1^m.70$	$0^m.88$
0.30	520	3.944	+1.18	0.97
0.35	390	3.978	+0.68	1.03
0.40	291	4.012	+0.18	1.07
0.45	218	4.045	-0.32	1.12
0.50	164	4.078	-0.81	1.14
0.55	125	4.111	-1.29	1.16
0.60	95	4.143	-1.77	1.17
0.65	73	4.174	-2.24	1.19
0.70	57	4.205	-2.71	1.21
0.75	44.4	4.235	-3.16	1.21
0.80	35.1	4.264	-3.61	1.22
0.85	28.0	4.292	-4.05	1.24

$X_c = 0.10$

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	790	3.896	$+1^m.68$	$1^m.09$
0.20	580	3.929	+1.17	1.17
0.35	432	3.963	+0.66	1.24
0.40	321	3.997	+0.15	1.30
0.45	240	4.030	-0.35	1.35
0.50	181	4.063	-0.84	1.39
0.55	137	4.096	-1.33	1.41
0.60	104	4.128	-1.81	1.43
0.65	80	4.160	-2.29	1.44
0.70	62	4.191	-2.76	1.46
0.75	48.5	4.221	-3.22	1.48
0.80	38.4	4.250	-3.67	1.50
0.85	30.6	4.278	-4.12	1.52

Table 1 (continued)
X = 0.70 Y = 0.27 Z = 0.03

$X_c = 0.60$

$\log \frac{M}{M_\odot}$	Age (million years)	Log T_e	M_{bol}	ΔM_{bol}
0.25	211	3.924	$+2^m.05$	$0^m.14$
0.30	159	3.961	+1.54	0.16
0.35	120	3.997	+1.05	0.16
0.40	90	4.032	+0.55	0.18
0.45	68	4.067	+0.07	0.19
0.50	52	4.101	-0.41	0.20
0.55	39.3	4.134	-0.89	0.20
0.60	30.1	4.166	-1.36	0.21
0.65	23.1	4.198	-1.82	0.20
0.70	17.9	4.228	-2.27	0.20
0.75	14.0	4.258	-2.72	0.21
0.80	11.0	4.287	-3.16	0.22
0.85	8.8	4.316	-3.59	0.22

$X_c = 0.50$

$\log \frac{M}{M_\odot}$	Age (million years)	log T_e	M_{bol}	ΔM_{bol}
0.25	390	3.915	$+2^m.00$	$0^m.30$
0.30	292	3.952	+1.49	0.32
0.35	219	3.987	+0.99	0.36
0.40	164	4.023	+0.49	0.37
0.45	124	4.057	0.00	0.39
0.50	93	4.091	-0.49	0.41
0.55	71	4.124	-0.97	0.42
0.60	54	4.157	-1.44	0.42
0.65	41.5	4.189	-1.91	0.43
0.70	32.1	4.219	-2.37	0.43
0.75	25.0	4.250	-2.82	0.43
0.80	19.7	4.279	-3.26	0.44
0.85	15.7	4.308	-3.70	0.45

$X_c = 0.40$

$\log \frac{M}{M_\odot}$	Age (million years)	log T_e	M_{bol}	ΔM_{bol}
0.25	540	3.904	$+1^m.96$	$0^m.48$
0.30	403	3.940	+1.45	0.53
0.35	301	3.976	+0.94	0.56
0.40	225	4.011	+0.44	0.59
0.45	169	4.045	-0.06	0.62
0.50	127	4.079	-0.55	0.64
0.55	96	4.113	-1.03	0.65
0.60	73	4.145	-1.51	0.67
0.65	56	4.177	-1.99	0.68
0.70	43.6	4.209	-2.45	0.68
0.75	33.9	4.239	-2.91	0.68
0.80	26.7	4.269	-3.36	0.69
0.85	21.2	4.297	-3.80	0.71

$X_c = 0.30$

$\log \frac{M}{M_\odot}$	Age (million years)	log T_e	M_{bol}	ΔM_{bol}
0.25	670	3.892	$+1^m.94$	$0^m.65$
0.30	497	3.927	+1.42	0.73
0.35	370	3.962	+0.91	0.77
0.40	276	3.997	+0.41	0.80
0.45	207	4.032	-0.10	0.83
0.50	155	4.066	-0.59	0.86
0.55	117	4.099	-1.08	0.89
0.60	89	4.132	-1.57	0.91
0.65	68	4.164	-2.05	0.93
0.70	53	4.196	-2.52	0.93
0.75	40.9	4.226	-2.98	0.94
0.80	32.2	4.256	-3.43	0.95
0.85	25.6	4.285	-3.88	0.97

$X_c = 0.20$

$\log \frac{M}{M_\odot}$	Age (million years)	log T_e	M_{bol}	ΔM_{bol}
0.25	770	3.878	$+1^m.93$	$0^m.85$
0.30	570	3.912	+1.41	0.93
0.35	426	3.947	+0.90	0.98
0.40	317	3.982	+0.38	1.04
0.45	237	4.016	-0.12	1.08
0.50	177	4.050	-0.63	1.12
0.55	134	4.083	-1.12	1.16
0.60	102	4.116	-1.61	1.18
0.65	78	4.149	-2.10	1.20
0.70	60	4.181	-2.57	1.21
0.75	46.6	4.212	-3.04	1.21
0.80	36.6	4.242	-3.50	1.23
0.85	29.0	4.271	-3.95	1.25

$X_c = 0.10$

$\log \frac{M}{M_\odot}$	Age (million years)	log T_e	M_{bol}	ΔM_{bol}
0.25	860	3.864	$+1^m.92$	$1^m.04$
0.30	640	3.899	+1.40	1.10
0.35	472	3.933	+0.89	1.18
0.40	351	3.967	+0.37	1.25
0.45	261	4.001	-0.14	1.30
0.50	195	4.035	-0.65	1.35
0.55	147	4.068	-1.15	1.40
0.60	112	4.101	-1.65	1.44
0.65	85	4.134	-2.14	1.46
0.70	66	4.166	-2.62	1.48
0.75	51	4.197	-3.09	1.49
0.80	40.1	4.227	-3.55	1.50
0.85	31.8	4.256	-4.01	1.52

Table 1 (continued)

X = 0.70 Y = 0.26 Z = 0.04

X_c = 0.60

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	228	3.899	$+2^m.20$	$0^m.15$
0.30	171	3.937	+1.70	0.15
0.35	128	3.974	+1.19	0.16
0.40	96	4.010	+0.69	0.18
0.45	72	4.045	+0.20	0.19
0.50	55	4.080	-0.29	0.20
0.55	41.4	4.114	-0.78	0.21
0.60	31.6	4.147	-1.25	0.22
0.65	24.2	4.179	-1.72	0.22
0.70	18.6	4.211	-2.19	0.21
0.75	14.5	4.242	-2.64	0.21
0.80	11.4	4.272	-3.09	0.22
0.85	9.0	4.301	-3.53	0.22

X_c = 0.50

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	422	3.981	$+2^m.16$	$0^m.29$
0.30	315	3.927	+1.65	0.34
0.35	235	3.964	+1.14	0.35
0.40	176	4.000	+0.63	0.37
0.45	132	4.035	+0.14	0.38
0.50	99	4.070	-0.36	0.40
0.55	75	4.104	-0.85	0.42
0.60	57	4.137	-1.33	0.44
0.65	43.6	4.170	-1.81	0.45
0.70	33.5	4.202	-2.28	0.44
0.75	26.0	4.233	-2.74	0.44
0.80	20.4	4.264	-3.19	0.45
0.85	16.1	4.293	-3.64	0.46

X_c = 0.40

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	590	3.880	$+2^m.13$	0.46
0.30	437	3.916	+1.62	0.51
0.35	324	3.952	+1.10	0.55
0.40	242	3.988	+0.59	0.59
0.45	181	4.023	+0.09	0.60
0.50	136	4.058	-0.41	0.62
0.55	102	4.092	-0.91	0.65
0.60	77	4.126	-1.40	0.67
0.65	59	4.159	-1.88	0.67
0.70	45.5	4.191	-2.35	0.68
0.75	35.2	4.222	-2.82	0.68
0.80	27.6	4.253	-3.28	0.70
0.85	21.8	4.282	-3.73	0.72

X_c = 0.30

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	730	3.867	$+2^m.12$	$0^m.64$
0.30	540	3.903	+1.60	0.70
0.35	400	3.939	+1.08	0.74
0.40	297	3.974	+0.57	0.78
0.45	221	4.009	+0.06	0.82
0.50	166	4.044	-0.45	0.85
0.55	124	4.078	-0.95	0.89
0.60	94	4.112	-1.45	0.91
0.65	72	4.145	-1.94	0.94
0.70	55	4.177	-2.42	0.95
0.75	42.7	4.209	-2.89	0.95
0.80	33.4	4.240	-3.35	0.96
0.85	26.4	4.269	-3.81	0.98

X_c = 0.20

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	850	3.853	$+2^m.12$	0.81
0.30	630	3.889	+1.60	0.87
0.35	462	3.924	+1.08	0.94
0.40	343	3.959	+0.56	1.00
0.45	255	3.994	+0.04	1.04
0.50	190	4.029	-0.47	1.08
0.55	143	4.063	-0.98	1.12
0.60	108	4.096	-1.48	1.16
0.65	82	4.129	-1.98	1.20
0.70	63	4.161	-2.47	1.23
0.75	48.6	4.193	-2.95	1.25
0.80	38.0	4.224	-3.42	1.26
0.85	30.1	4.254	-3.87	1.27

X_c = 0.10

$\log \frac{M}{M_\odot}$	Age (million years)	$\log T_e$	M_{bol}	ΔM_{bol}
0.25	950	3.838	$+2^m.11$	$1^m.01$
0.30	700	3.874	+1.58	1.09
0.35	510	3.909	+1.06	1.16
0.40	379	3.944	+0.54	1.22
0.45	281	3.979	+0.02	1.27
0.50	209	4.014	-0.50	1.31
0.55	157	4.048	-1.01	1.36
0.60	119	4.081	-1.51	1.41
0.65	90	4.114	-2.01	1.45
0.70	69	4.146	-2.50	1.48
0.75	53	4.178	-2.99	1.51
0.80	41.8	4.209	-3.47	1.53
0.85	33.0	4.239	-3.93	1.54

Table 2

Zero-age lines for six different initial chemical compositions

	.60 .38 .02	.60 .37 .03	.60 .36 .04	.70 .28 .02	.70 .27 .03	.70 .26 .04
log T_e	M_{bol}	M_{bol}	M_{bol}	M_{bol}	M_{bol}	M_{bol}
3.90					$+2^m.49$	$+2^m.34$
3.91			$+2^m.39$	$+2^m.58$	+2.36	+2.21
3.92			+2.26	+2.46	+2.24	+2.08
3.93		$+2^m.31$	+2.13	+2.33	+2.11	+1.95
3.94		+2.18	+2.00	+2.20	+1.98	+1.81
3.95	$+2^m.28$	+2.04	+1.37	+2.07	+1.84	+1.68
3.96	+2.15	+1.91	+1.74	+1.94	+1.71	+1.55
3.97	+2.01	+1.77	+1.60	+1.81	+1.58	+1.41
3.98	+1.88	+1.64	+1.47	+1.68	+1.45	+1.27
3.99	+1.74	+1.50	+1.33	+1.55	+1.31	+1.13
4.00	+1.61	+1.37	+1.20	+1.41	+1.17	+1.00
4.01	+1.47	+1.23	+1.06	+1.28	+1.04	+0.87
4.02	+1.33	+1.09	+0.92	+1.14	+0.90	+0.73
4.03	+1.19	+0.95	+0.78	+1.00	+0.76	+0.59
4.04	+1.05	+0.81	+0.64	+0.87	+0.63	+0.46
4.05	+0.91	+0.67	+0.50	+0.73	+0.49	+0.32
4.06	+0.77	+0.53	+0.36	+0.59	+0.35	+0.18
4.07	+0.63	+0.39	+0.22	+0.44	+0.22	+0.04
4.08	+0.49	+0.25	+0.08	+0.30	+0.08	+0.09
4.09	+0.35	+0.11	-0.06	+0.16	-0.06	-0.23
4.10	+0.20	-0.03	-0.20	+0.02	-0.20	-0.37
4.11	+0.06	-0.17	-0.34	-0.12	-0.34	-0.51
4.12	-0.08	-0.31	-0.48	-0.26	-0.49	-0.65
4.13	-0.22	-0.45	-0.62	-0.41	-0.63	-0.79
4.14	-0.37	-0.60	-0.77	-0.56	-0.77	-0.93
4.15	-0.51	-0.74	-0.91	-0.70	-0.92	-1.08
4.16	-0.65	-0.88	-1.06	-0.85	-1.06	-1.22
4.17	-0.80	-1.03	-1.20	-0.99	-1.20	-1.36
4.18	-0.94	-1.17	-1.34	-1.13	-1.35	-1.51
4.19	-1.09	-1.31	-1.49	-1.28	-1.50	-1.66
4.20	-1.23	-1.46	-1.63	-1.42	-1.65	-1.81
4.21	-1.38	-1.61	-1.77	-1.57	-1.80	-1.96
4.22	-1.52	-1.76	-1.92	-1.72	-1.95	-2.11
4.23	-1.67	-1.91	-2.07	-1.87	-2.10	-2.26
4.24	-1.82	-2.06	-2.22	-2.03	-2.24	-2.40
4.25	-1.97	-2.21	-2.37	-2.18	-2.39	-2.54
4.26	-2.13	-2.36	-2.52	-2.33	-2.54	-2.69
4.27	-2.28	-2.51	-2.67	-2.48	-2.68	-2.84
4.28	-2.43	-2.66	-2.81	-2.63	-2.83	-2.98
4.29	-2.59	-2.81	-2.96	-2.78	-2.98	-3.13
4.30	-2.74	-2.96	-3.11	-2.93	-3.13	-3.29
4.31	-2.89	-3.11	-3.26	-3.08	-3.28	-3.44
4.32	-3.05	-3.26	-3.41	-3.24	-3.44	
4.33	-3.20	-3.42	-3.56	-3.39		
4.34	-3.36	-3.57	-3.71	-3.55		
4.35	-3.51	-3.72	-3.86			

Table 3

Zero-age lines for different values of the relative hydrogen content X and the helium-metal ratio Y/Z

$\log T_e$	X = 0.60 Y/Z = 19.0 M_{bol}	X = 0.60 Y/Z = 14.0 M_{bol}	X = 0.70 Y/Z = 14.0 M_{bol}	X = 0.60 Y/Z = 9.0 M_{bol}	X = 0.70 Y/Z = 9.0 M_{bol}	X = 0.70 Y/Z = 6.5 M_{bol}	Observational zero-age line (cf. B. Strömgren, Rev. Mod. Phys. 36, 532, 1964) M_{bol}
3.97	$+2^m.01$	$+1^m.83$	$+1^m.81$	$+1^m.60$	$+1^m.58$	$+1^m.41$	$+1^m.7$
4.02	+1.33	+1.15	+1.14	+0.92	+0.90	+0.73	+0.8
4.07	+0.63	+0.45	+0.44	+0.22	+0.22	+0.04	0.0
4.12	-0.08	-0.25	-0.26	-0.48	-0.49	-0.65	-0.7
4.17	-0.80	-0.97	-0.99	-1.20	-1.20	-1.36	-1.4
4.22	-1.52	-1.70	-1.72	-1.92	-1.95	-2.11	-2.1
4.27	-2.28	-2.45	-2.48	-2.67	-2.68	-2.84	-2.8
4.32	-3.05	-3.21	-3.24	-3.41	-3.44	-3.60	-3.5

Table 4

Mass-luminosity relation on the zero-age line for different values of the relative hydrogen content X and the helium-metal ratio Y/Z

$\log \frac{M}{M_\odot}$	X = 0.60 Y/Z = 19.0 M_{bol}	X = 0.60 Y/Z = 14.0 M_{bol}	X = 0.70 Y/Z = 14.0 M_{bol}	X = 0.60 Y/Z = 9.0 M_{bol}	X = 0.70 Y/Z = 9.0 M_{bol}	X = 0.70 Y/Z = 6.5 M_{bol}
0.25	$+1^m.40$	$+1^m.53$	$+1^m.93$	$+1^m.71$	$+2^m.11$	$+2^m.26$
0.35	+0.43	+0.55	+0.95	+0.71	+1.12	+1.26
0.45	-0.51	-0.41	0.00	-0.26	+0.15	+0.28
0.55	-1.42	-1.33	-0.93	-1.21	-0.80	-0.68
0.65	-2.31	-2.24	-1.83	-2.13	-1.72	-1.62
0.75	-3.17	-3.10	-2.70	-3.02	-2.61	-2.53
0.85	-4.00	-3.95	-3.55	-3.87	-3.47	-3.41

Table 5

X = 0.60 Y = 0.38 Z = 0.02

log Age (years)	X_c = 0.50 log T_e	ΔM_{bol}	X_c = 0.40 log T_e	ΔM_{bol}	X_c = 0.30 log T_e	ΔM_{bol}	X_c = 0.20 log T_e	ΔM_{bol}	X_c = 0.10 log T_e	ΔM_{bol}
8.70							3.940	0.83	3.941	1.08
8.60					3.958	0.61	3.967	0.87	3.968	1.11
8.50			3.960	0.38	3.985	0.64	3.993	0.90	3.994	1.14
8.40			3.988	0.40	4.012	0.66	4.020	0.93	4.021	1.17
8.30	3.953	0.15	4.016	0.42	4.039	0.67	4.046	0.95	4.047	1.20
8.20	3.981	0.18	4.043	0.43	4.066	0.68	4.073	0.96	4.074	1.22
8.10	4.010	0.20	4.070	0.44	4.093	0.69	4.100	0.97	4.101	1.23
8.00	4.038	0.20	4.097	0.45	4.121	0.70	4.127	0.98	4.128	1.24
7.90	4.065	0.21	4.124	0.46	4.148	0.72	4.154	1.00	4.156	1.26
7.80	4.093	0.21	4.151	0.47	4.175	0.74	4.182	1.01	4.183	1.28
7.70	4.121	0.21	4.179	0.47	4.202	0.75	4.210	1.03	4.211	1.30
7.60	4.148	0.22	4.206	0.48	4.229	0.75	4.237	1.04	4.239	1.30
7.50	4.175	0.22	4.233	0.48	4.256	0.75	4.265	1.03	4.268	1.31
7.40	4.202	0.23	4.260	0.47	4.284	0.74	4.294	1.03	4.297	1.32
7.30	4.229	0.24	4.288	0.47	4.313	0.74	4.323	1.03	4.326	1.33
7.20	4.256	0.23	4.316	0.48	4.343	0.73	4.352	1.03	4.355	1.34
7.10	4.284	0.22	4.344	0.47						
7.00	4.311	0.22	4.373	0.47						
6.90	4.339	0.22								
6.80	4.368	0.21								

X = 0.60 Y = 0.37 Z = 0.03

log Age (years)	X_c = 0.50 log T_e	ΔM_{bol}	X_c = 0.40 log T_e	ΔM_{bol}	X_c = 0.30 log T_e	ΔM_{bol}	X_c = 0.20 log T_e	ΔM_{bol}	X_c = 0.10 log T_e	ΔM_{bol}
8.80							3.892	0.79	3.894	1.03
8.70					3.909	0.61	3.919	0.83	3.920	1.06
8.60					3.936	0.62	3.946	0.86	3.947	1.10
8.50			3.939	0.38	3.964	0.62	3.973	0.88	3.974	1.13
8.40			3.967	0.40	3.992	0.64	4.000	0.90	4.001	1.15
8.30	3.931	0.19	3.995	0.41	4.019	0.66	4.027	0.93	4.028	1.17
8.20	3.960	0.19	4.023	0.42	4.046	0.68	4.054	0.95	4.055	1.19
8.10	3.989	0.20	4.050	0.43	4.074	0.69	4.081	0.96	4.083	1.21
8.00	4.017	0.21	4.078	0.44	4.101	0.71	4.109	0.98	4.110	1.23
7.90	4.045	0.21	4.105	0.45	4.128	0.72	4.137	0.99	4.138	1.24
7.80	4.073	0.21	4.133	0.46	4.156	0.73	4.164	1.00	4.166	1.26
7.70	4.101	0.22	4.161	0.47	4.184	0.74	4.192	1.02	4.194	1.28
7.60	4.129	0.22	4.188	0.48	4.212	0.75	4.220	1.02	4.222	1.29
7.50	4.156	0.23	4.215	0.48	4.240	0.74	4.249	1.02	4.251	1.30
7.40	4.184	0.23	4.243	0.48	4.269	0.73	4.278	1.03	4.280	1.31
7.30	4.211	0.23	4.272	0.48	4.298	0.73	4.308	1.03	4.310	1.33
7.20	4.239	0.23	4.301	0.48	4.328	0.73	4.339	1.03		
7.10	4.267	0.23	4.330	0.47	4.357	0.74				
7.00	4.296	0.22	4.360	0.47						
6.90	4.324	0.22								
6.80	4.354	0.22								

Table 5 (continued)

X = 0.60 Y = 0.36 Z = 0.04

log Age (years)	X_c = 0.50 log T_e	ΔM_{bol}	X_c = 0.40 log T_e	ΔM_{bol}	X_c = 0.30 log T_e	ΔM_{bol}	X_c = 0.20 log T_e	ΔM_{bol}	X_c = 0.10 log T_e	ΔM_{bol}
.80							3.877	$0^m.72$	3.881	$0^m.94$
8.70					3.894	$0^m.54$	3.904	0.78	3.907	1.00
8.60			3.894	$0^m.34$	3.922	0.58	3.931	0.83	3.933	1.05
8.50			3.923	0.36	3.949	0.61	3.958	0.87	3.960	1.10
8.40			3.952	0.39	3.977	0.64	3.986	0.90	3.987	1.14
8.30	3.916	$0^m.16$	3.980	0.41	4.005	0.66	4.013	0.92	4.014	1.17
8.20	3.945	0.18	4.008	0.43	4.032	0.68	4.041	0.94	4.041	1.19
8.10	3.973	0.20	4.036	0.44	4.060	0.69	4.068	0.96	4.068	1.21
8.00	4.002	0.20	4.064	0.44	4.087	0.70	4.095	0.97	4.096	1.23
7.90	4.030	0.21	4.091	0.45	4.115	0.71	4.123	0.98	4.123	1.25
7.80	4.058	0.22	4.119	0.46	4.143	0.72	4.151	1.00	4.151	1.27
7.70	4.087	0.22	4.147	0.47	4.171	0.74	4.179	1.01	4.180	1.28
7.60	4.115	0.22	4.175	0.48	4.199	0.74	4.208	1.02	4.209	1.29
7.50	4.143	0.22	4.203	0.48	4.227	0.74	4.237	1.03	4.237	1.31
7.40	4.171	0.22	4.231	0.48	4.256	0.74	4.266	1.04	4.267	1.33
7.30	4.199	0.23	4.260	0.48	4.286	0.75	4.296	1.05	4.298	1.35
7.20	4.227	0.23	4.289	0.48	4.316	0.76	4.326	1.07		
7.10	4.255	0.23	4.319	0.48						
7.00	4.284	0.23	4.350	0.48						
6.90	4.313	0.23								
6.80	4.343	0.24								

X = 0.70 Y = 0.28 Z = 0.02

log Age (years)	X_c = 0.60 log T_e	ΔM_{bol}	X_c = 0.50 log T_e	ΔM_{bol}	X_c = 0.40 log T_e	ΔM_{bol}	X_c = 0.30 log T_e	ΔM_{bol}	X_c = 0.20 log T_e	ΔM_{bol}	X_c = 0.10 log T_e	ΔM_{bol}
8.90											3.895	$1^m.09$
8.80					3.907	$0^m.46$	3.920	$0^m.68$	3.923	$0^m.91$	3.920	1.13
8.70			3.904	$0^m.28$	3.936	0.49	3.948	0.72	3.949	0.98	3.946	1.21
8.60			3.934	0.30	3.964	0.53	3.975	0.77	3.976	1.03	3.972	1.26
8.50			3.963	0.32	3.991	0.56	4.002	0.81	4.002	1.06	3.999	1.30
8.40	3.921	$0^m.14$	3.992	0.35	4.019	0.58	4.029	0.83	4.029	1.10	4.025	1.34
8.30	3.952	0.16	4.020	0.37	4.046	0.60	4.056	0.85	4.055	1.13	4.052	1.37
8.20	3.982	0.18	4.048	0.39	4.073	0.62	4.083	0.87	4.082	1.14	4.079	1.40
8.10	4.011	0.18	4.076	0.39	4.100	0.63	4.110	0.89	4.110	1.16	4.106	1.42
8.00	4.040	0.18	4.103	0.40	4.127	0.64	4.137	0.90	4.137	1.17	4.133	1.43
7.90	4.068	0.18	4.130	0.41	4.155	0.65	4.164	0.91	4.164	1.18	4.161	1.44
7.80	4.096	0.18	4.157	0.41	4.182	0.66	4.192	0.92	4.192	1.20	4.189	1.46
7.70	4.123	0.19	4.184	0.42	4.209	0.67	4.219	0.93	4.220	1.21	4.217	1.48
7.60	4.151	0.19	4.211	0.42	4.236	0.67	4.247	0.94	4.248	1.21	4.246	1.50
7.50	4.178	0.20	4.238	0.42	4.264	0.68	4.275	0.94	4.277	1.23	4.274	1.52
7.40	4.205	0.20	4.266	0.42	4.292	0.67	4.304	0.95	4.305	1.25	4.303	1.54
7.30	4.233	0.20	4.294	0.43	4.321	0.67	4.332	0.95				
7.20	4.260	0.20	4.322	0.43								
7.10	4.287	0.20										
7.00	4.315	0.21										
6.90	4.343	0.20										

Table 5 (continued)

X = 0.70 Y = 0.27 Z = 0.03

	X_c = 0.60		X_c = 0.50		X_c = 0.40		X_c = 0.30		X_c = 0.20		X_c = 0.10	
log Age (years)	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}
8.90									3.875	$0^m.84$	3.874	$1^m.06$
8.80							3.899	$0^m.67$	3.901	0.90	3.900	1.10
8.70			3.882	$0^m.27$	3.913	$0^m.49$	3.926	0.73	3.928	0.95	3.926	1.16
8.60			3.912	0.30	3.941	0.53	3.953	0.76	3.955	0.99	3.953	1.22
8.50	3.868	$0^m.12$	3.941	0.31	3.970	0.56	3.981	0.79	3.982	1.04	3.979	1.27
8.40	3.900	0.13	3.970	0.34	3.997	0.58	4.008	0.81	4.009	1.07	4.006	1.31
8.30	3.931	0.14	3.999	0.36	4.025	0.60	4.036	0.83	4.036	1.10	4.033	1.35
8.20	3.961	0.16	4.027	0.37	4.053	0.62	4.064	0.86	4.063	1.13	4.060	1.39
8.10	3.991	0.16	4.055	0.39	4.080	0.64	4.091	0.88	4.090	1.16	4.087	1.43
8.00	4.019	0.17	4.083	0.41	4.108	0.65	4.118	0.90	4.118	1.18	4.115	1.45
7.90	4.048	0.18	4.110	0.42	4.136	0.67	4.146	0.92	4.146	1.20	4.143	1.47
7.80	4.076	0.19	4.138	0.42	4.163	0.68	4.174	0.93	4.174	1.21	4.17_	1.48
7.70	4.105	0.20	4.166	0.42	4.191	0.68	4.202	0.93	4.203	1.21	4.199	1.49
7.60	4.133	0.20	4.194	0.43	4.220	0.68	4.230	0.94	4.231	1.22	4.228	1.50
7.50	4.160	0.21	4.221	0.43	4.240	0.68	4.258	0.95	4.260	1.24	4.257	1.52
7.40	4.188	0.20	4.249	0.43	4.276	0.69	4.287	0.97	4.289	1.26	4.286	1.53
7.30	4.215	0.20	4.278	0.44	4.304	0.71						
7.20	4.243	0.20	4.307	0.45								
7.10	4.271	0.21										
7.00	4.299	0.22										
6.90	4.327	0.22										

X = 0.70 Y = 0.26 Z = 0.04

	X_c = 0.60		X_c = 0.50		X_c = 0.40		X_c = 0.30		X_c = 0.20		X_c = 0.10	
log Age (years)	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}	log T_e	ΔM_{bol}
8.90							3.856	$0^m.62$	3.861	$0^m.82$	3.858	$1^m.06$
8.80					3.871	$0^m.45$	3.884	0.67	3.888	0.87	3.885	1.11
8.70			3.869	$0^m.27$	3.899	0.49	3.912	0.71	3.915	0.9[illegible]	3.912	1.16
8.60			3.898	0.30	3.927	0.52	3.940	0.74	3.942	0.97	3.938	1.21
8.50	3.855	$0^m.12$	3.926	0.34	3.955	0.55	3.967	0.77	3.969	1.01	3.965	1.25
8.40	3.886	0.14	3.955	0.35	3.983	0.57	3.994	0.80	3.996	1.04	3.992	1.29
8.30	3.916	0.15	3.984	0.36	4.011	0.59	4.021	0.83	4.023	1.07	4.020	1.32
8.20	3.946	0.15	4.013	0.37	4.039	0.61	4.049	0.86	4.051	1.11	4.047	1.36
8.10	3.976	0.16	4.041	0.38	4.067	0.63	4.077	0.89	4.078	1.14	4.074	1.40
8.00	4.005	0.18	4.069	0.40	4.095	0.65	4.105	0.91	4.105	1.17	4.102	1.43
7.90	4.033	0.19	4.097	0.42	4.123	0.67	4.133	0.93	4.133	1.20	4.130	1.46
7.80	4.062	0.19	4.125	0.43	4.151	0.67	4.161	0.94	4.161	1.23	4.158	1.49
7.70	4.090	0.20	4.153	0.44	4.179	0.68	4.189	0.95	4.189	1.25	4.186	1.52
7.60	4.119	0.21	4.181	0.45	4.207	0.68	4.218	0.95	4.218	1.26	4.215	1.53
7.50	4.147	0.22	4.209	0.44	4.236	0.69	4.247	0.96	4.247	1.27	4.244	1.54
7.40	4.174	0.22	4.237	0.44	4.265	0.71	4.276	0.98	4.277	1.28	4.273	1.55
7.30	4.202	0.21	4.266	0.44	4.293	0.73						
7.20	4.231	0.21	4.295	0.45								
7.10	4.259	0.22										
7.00	4.288	0.22										

Table 6

Relation between age and effective temperature, valid for the upper 40 per cent of the main-sequence band (ΔM_{bol} larger than about 1 magnitude), where the relation is found to be practically independent of of the absolute magnitude.

log Age (years)	X = 0.70 Y = 0.27 Z = 0.03 log T_e	X = 0.60 Y = 0.37 Z = 0.03 log T_e	X = 0.60 Y = 0.36 Z = 0.04 log T_e
8.80	3.900	3.893	3.879
8.70	3.927	3.920	3.906
8.60	3.954	3.947	3.932
8.50	3.981	3.974	3.959
8.40	4.008	4.001	3.987
8.30	4.035	4.028	4.014
8.20	4.062	4.055	4.041
8.10	4.089	4.082	4.068
8.00	4.117	4.110	4.096
7.90	4.145	4.138	4.123
7.80	4.173	4.165	4.151
7.70	4.201	4.193	4.180
7.60	4.230	4.221	4.209
7.50	4.258	4.250	4.237
7.40	4.287	4.279	4.267
7.30	4.316	4.309	4.297

Table 7

Relation between the color indices $(U-B)_o$ and $(u-b)_o$ for the upper 40 per cent of the main-sequence band (cf. B. Strömgren, Rev. Mod. Phys. 36, 532, 1964). The age corresponding to X = 0.70, Y = 0.27, Z = 0.03 is also given.

$(U-B)_o$	$(u-b)_o$	log T_e	X = 0.70 Y = 0.27 Z = 0.03 log Age (years)
$-0^m.80$	$+0^m.16$	4.329	7.26
-0.70	+0.31	4.275	7.44
-0.60	+0.46	4.222	7.63
-0.50	+0.62	4.172	7.80
-0.40	+0.79	4.128	7.9[illegible]
-0.30	+0.97	4.087	8.1[illegible]

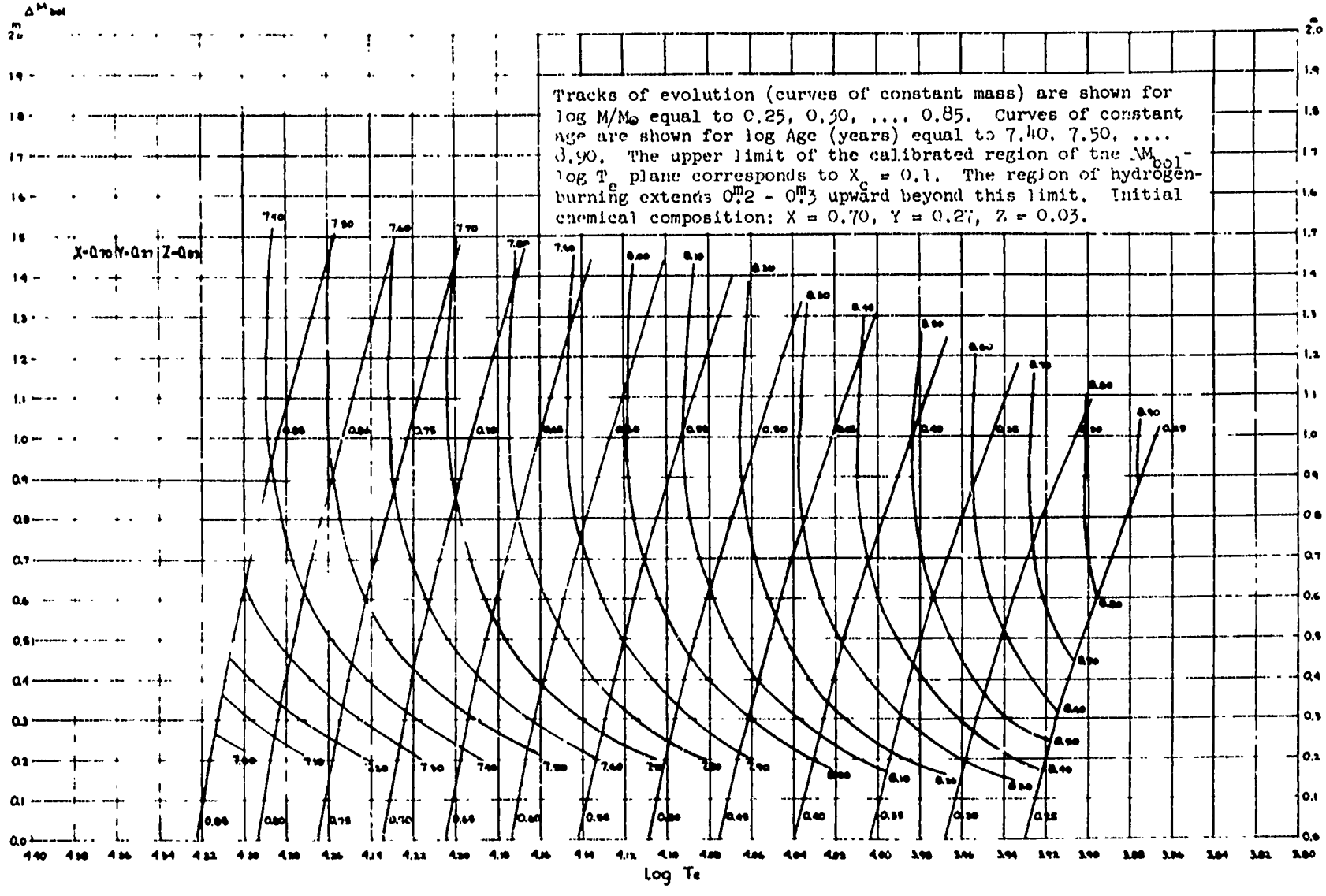
Tracks of evolution (curves of constant mass) are shown for log M/M⊙ equal to 0.25, 0.30, ... 0.85. Curves of constant age are shown for log Age (years) equal to 7.40, 7.50, ... 8.90. The upper limit of the calibrated region of the M_{bol} - log T_e plane corresponds to X_c = 0.1. The region of hydrogen-burning extends $0^m.2$ - $0^m.3$ upward beyond this limit. Initial chemical composition: X = 0.70, Y = 0.27, Z = 0.03.
X=0.70 Y=0.27 Z=0.03
ΔM_{bol}
Log Te

Fig. 1

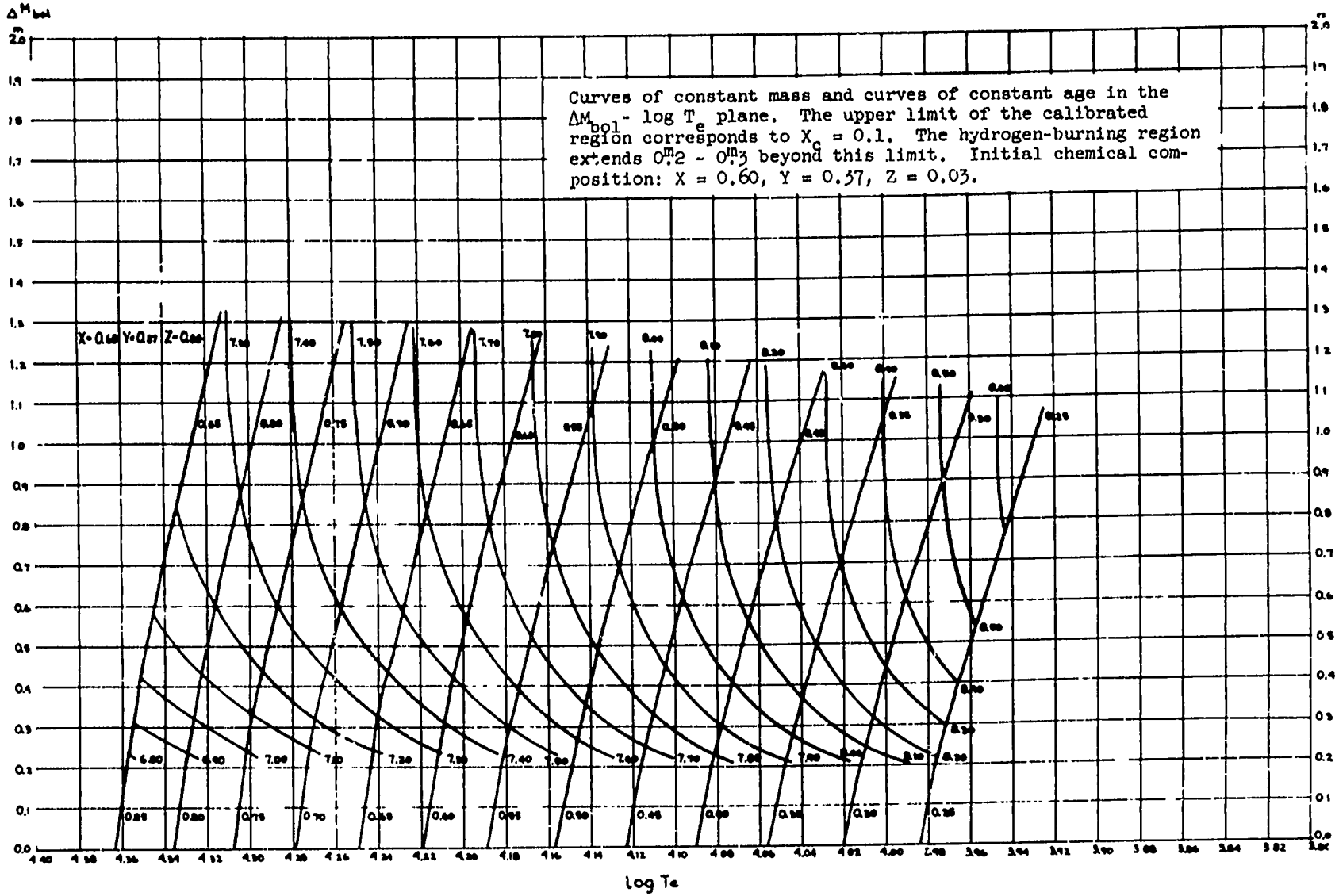
Curves of constant mass and curves of constant age in the ΔM_{bol} - log T_e plane. The upper limit of the calibrated region corresponds to X_c = 0.1. The hydrogen-burning region extends $0^m.2$ - $0^m.3$ beyond this limit. Initial chemical composition: X = 0.60, Y = 0.37, Z = 0.03.
log Te

Fig.2

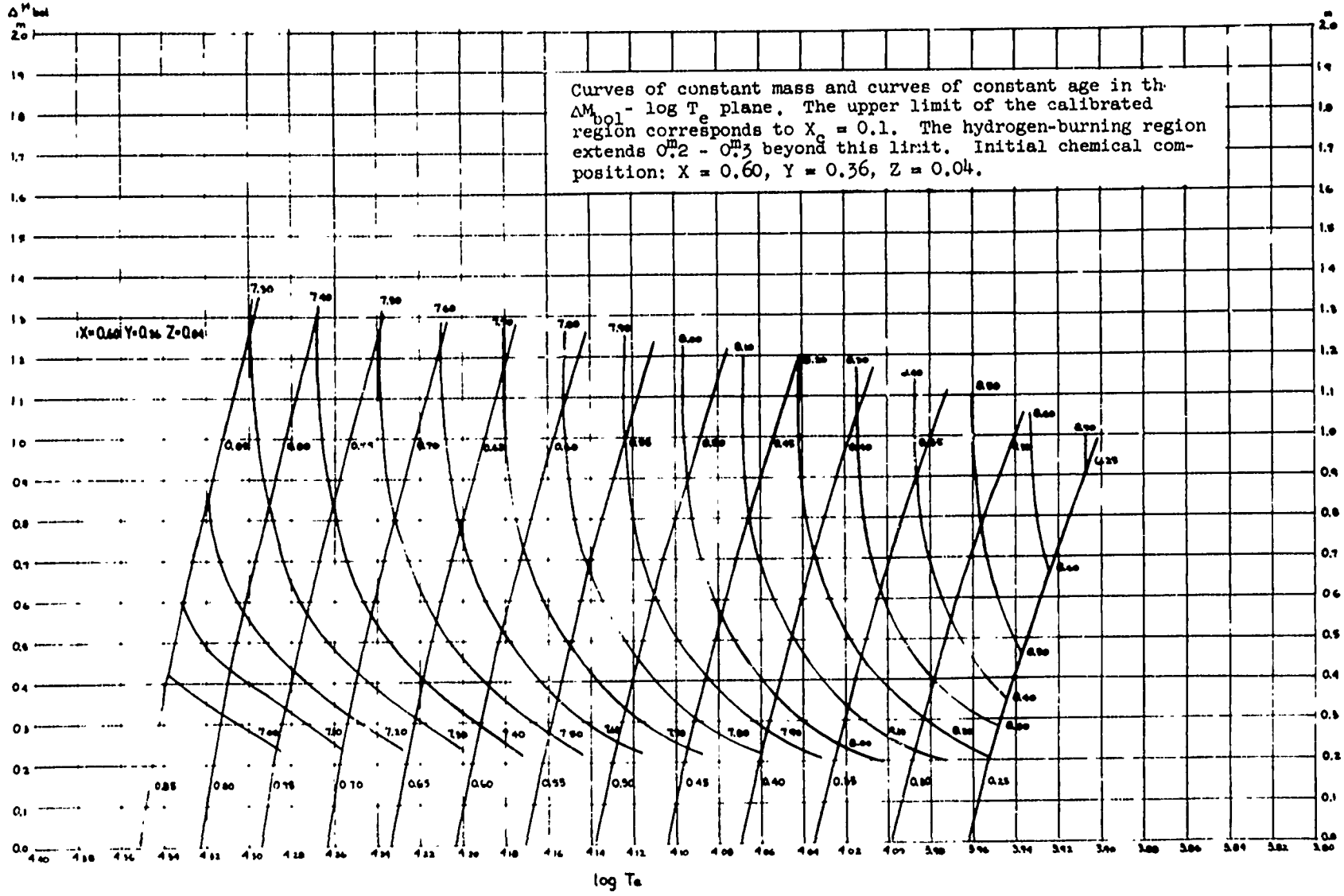
Curves of constant mass and curves of constant age in the ΔM_{bol} - log T_e plane. The upper limit of the calibrated region corresponds to X_c = 0.1. The hydrogen-burning region extends $0^m.2$ - $0^m.3$ beyond this limit. Initial chemical composition: X = 0.60, Y = 0.36, Z = 0.04.
X=0.60 Y=0.36 Z=0.04
log T_e

Fig. 3